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WIND–TUNNEL INVESTIGATION OF A BEVELED AILERON SHAPE

DESIGNED TO INCREASE THE USEFUL DEFLECTION RANGE

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NACA

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MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

WIND-TUNNEL INVESTIGATION OF A BEVELED AILERON SHAPE

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INTRODUCTION

The useful range of deflection of a control surface is ordinarily limited by the occurrence of flow separation on the convex side of the surface behind the hinge. After this separation occurs the hinge moment increases rapidly, making it extremely difficult to deflect the aileron beyond this point at high speed. An aileron following the shape of the original airfoil forms an outside corner on one side of the flap hinge when it is deflected through a small angle. The increased local velocity around this corner, which is followed by an adverse pressure gradient, is responsible for the flow separation.

When beveled ailerons were constructed for the XP-51 airplane, the bevel was built up by spreading the upper and lower surfaces apart behind the hinge (see fig. 1, configuration B, and fig. 2 of reference 1), making a slight inside corner on each surface. During the flight tests, it was noted that these ailerons showed a somewhat greater useful range of deflections and gave slightly better control at low speed than did the original ailerons.

In an attempt to further increase the useful range of angular deflections, the aileron shown in figure 1, configuration C, was designed. The more pronounced inside corner at the aileron hinge point causes an initial positive pressure peak, so that a certain amount of deflection is possible before the pressure curve becomes flat. The purpose of the present investigation made in the Langley Memorial Aeronautical Laboratory two-dimensional low-turbulence tunnel was to determine the general

aerodynamic characteristics of this aileron and, in particular, to determine its useful angular range.

APPARATUS AND METHODS

A scale model having a 36-inch wing chord and 35.75-inch span was made to correspond to the measured ordinates of an intermediate section of the aileron portion of the wing (16 inches outboard from the inboard end of the right aileron) of the XP-51 airplane. The wing section was modified aft of the 70-percent chord point in order to fair in the 0.150-chord aileron. (See fig. 1, configuration C.) The ordinates of the modified wing section forward of the aileron hinge line and the original measured ordinates of the plain wing are given in table I.

The aileron shapes tested are shown in figure 2. The three ailerons were hinged at the 85-percent chord point. Therefore, with the 0.145-chord aileron the wing chord was reduced approximately 0.2 inch. In the sealed condition, the aileron nose gap was sealed with thin rubber dam.

For the low-drag condition, the model was finished with number 400 waterpaper to produce aerodynamically smooth surfaces. For the high-drag condition, the model surfaces were the same as in the low-drag condition; but roughness strips, made of carborundum grains embedded in glue on a 1-inch strip of Scotch tape, were placed on the upper and lower surfaces near the leading edge of the model.

Lift and drag measurements of the model were made by the methods described in reference 2. The profile-drag and lift coefficients were based on a nominal wing chord of 36 inches. The aileron hinge moments were measured by means of a calibrated torque rod and the coefficient is based on the actual chord and span of the aileron.

All tests were made at a dynamic pressure of 59.7 pounds per square foot, which corresponds to a velocity of about 150 miles per hour and a test Reynolds number of approximately 4,000,000. The test program is given in the following table.

Aileron deflection, $\pm 30^\circ$, for all runs				
Run no.	Aileron	α_0 (deg)	Gap condition	Surface condition
1	1	0	Seal	Smooth
2	1	0	No seal	Smooth
3	1	0	Seal	Roughness strips
4	2	0	Seal	Smooth
5	2	0	Seal	Roughness strips
6	3	0	Seal	Smooth
7	3	0	Seal	Roughness strips
8	3	$0, \pm 4.1$ 8.3	Seal	Roughness strips

RESULTS AND DISCUSSION

Effect of hinge-gap seal.- The effects of sealing the hinge gap on the aileron characteristics can be seen from the results presented in figure 3. With the gap open there is a tendency for aileron 1 to overbalance for small deflections. A similar tendency has been found in other tests on beveled-trailing-edge ailerons. As shown in figure 3, this tendency to overbalance was eliminated by sealing the gap to stop the flow of air. Apparently the pressure difference resulting from a small deflection of the aileron is sufficient to cause a large portion of the boundary layer to flow from one side of the airfoil to the other through the hinge gap, accentuating the effect of the bevel. In addition to eliminating the overbalance, sealing the gap also reduced the increment in lift for the larger aileron deflections. This is not in agreement with the usually favorable effect of sealing the gap of contour ailerons or less severely shaped ailerons. In a practical installation the effect of the hinge gap may, of course, be influenced by the internal pressure in the wing.

Effect of surface condition and Reynolds number.-
Because the balancing action of the bevel depends on the
boundary-layer thickness and profile, it is to be
expected that the amount of balance obtained may vary
considerably with surface roughness and Reynolds number.
Because the boundary-layer thickness near the trailing
edge of the airfoil is intimately related to the drag
coefficient and because the form of the boundary-layer
profile near the trailing edge varies little for thin
airfoils at small angles of attack, it is to be expected
that the balancing action of the bevel can be related
to the drag coefficient of the section. The effects of
Reynolds number, position of transition, and surface
condition on aileron characteristics may therefore be
correlated with their known effects on profile drag.

The effect of changes in profile drag on the aileron
characteristics is indicated by the results presented
in figure 4. The presence of the roughness strips
approximately doubles the drag of the airfoil section
in each case. A comparison between the high- and low-
drag conditions for the three configurations shows that
the slope of the hinge-moment curve is reduced for small
deflections and the increment of lift is reduced for
almost all aileron deflections by the addition of the
roughness strips near the leading edge of the model.

For a conservative design, the control surface
should be proportioned so as to avoid overbalance with
the highest profile-drag coefficient the wing would be
expected to have in service.

Although these results (fig. 4) may be taken as an
indication of the effect of drag on a moderately thin
airfoil, it is not thought that the results can be
safely applied to airfoils of greater thickness. On
thicker airfoils the boundary layer at the trailing
edge is often considerably nearer the separation point,
and the behavior of the aileron under these circum-
stances may be quite different.

Effect of aileron profile.- The effects of aileron
profile on the aileron characteristics are presented in
figures 4 and 5.

In figure 4(a) the hinge moment and lift charac-
teristics are given for aileron 1, which had a trailing-
edge bevel angle of 27°. In the smooth condition, the

results show that for this moderate bevel angle the
hinge-moment and lift characteristics are approximately
linear until a down deflection of 25° is reached. For
upward deflections near -10°, an abrupt change occurs
in the slope of the hinge-moment curve. Although
aileron 1 would give the required lateral control at
low speeds, the large negative value (-0.0053) of
$(\partial c_h / \partial \delta_a)_\alpha$ combined with the characteristic positive

value of $(\partial c_h / \partial \alpha)_{\delta_a}$ for beveled-trailing-edge ailerons

would result in too large stick forces at high speeds
to suit present-day control requirements. The results
in figure 4(b), wing smooth, show that aileron 2 with
a bevel angle of 30°, an increase of 3° in the bevel
angle of aileron 1, would also fail to give the required
lateral control at high speed because of the too large
negative value (-0.0044) of $(\partial c_h / \partial \delta_a)_\alpha$. The results in
figure 4(c), wing smooth, show that aileron 3 with a
bevel angle of 33°, an increase of 3° in the bevel angle
of aileron 2, combined with a reduction in aileron chord
of 0.005c had a value of -0.0020 for $(\partial c_h / \partial \delta_a)_\alpha$ which

should be low enough to give the required lateral control
at high speeds on a pursuit plane of conventional size.

A comparison of figures 4(a), 4(b), and 4(c) shows
that by increasing the bevel angle from 27° to 33° the
slope of the hinge-moment curve is progressively reduced
at small deflections, resulting in considerable curva-
ture of the hinge-moment curve, while the lift-
characteristic curves remain about the same for the
three ailerons.

No contour aileron was tested for comparison with
the modified aileron; hence, it is not possible to
state definitely that the results of these tests show
an increase in the range of useful deflection over the
usual contour aileron, although low values of the hinge
moment appear to be extended to greater deflections than
is ordinarily found for conventional shapes.

Figure 5 gives a comparison of drag polars for the
modified aileron section and the plain wing section
with and without a 0.187c contour aileron. This com-
parison shows that in the range of test Reynolds number
an increase in minimum profile drag $c_{d_{o_{min}}}$ of about

0.0002 resulted from deforming the plain section with a contour aileron to form the modified section and aileron.

Because the results given in figure 6, wing leading edge rough, showed that a 35° bevel angle would just balance out the aileron hinge moments with the model at 0° angle of attack, tests were made to determine the characteristics of aileron 3 with the model, leading edge rough, at other angles of attack. These results (fig. 6) show that, as the angle of attack was increased from 0° to 4.1° and to 8.3°, aileron 3 showed positive hinge-moment slopes in the negative deflection range. It will be noted, however, that the combination of right and left ailerons is not overbalanced.

Langley Memorial Aeronautical Laboratory,
     National Advisory Committee for Aeronautics,
          Langley Field, Va., April 8, 1944.

REFERENCES

1. White, M. D., and Hoover, Herbert H.: Flight Tests
   of Modifications to Improve the Aileron Control
   Characteristics of a North American XP-51 Airplane
   (A.C. No. 41-38). NACA MR, June 20, 1942.

2. Abbott, Ira H., von Doenhoff, Albert E., and
   Stivers, Louis S., Jr.: Summary of Airfoil Data.
   NACA ACR No. L5C05, 1945.

3. Abbott, Frank T., Jr., and Underwood, William J.:
   Wind-Tunnel Investigation of Profile Drag and
   Lift of an Intermediate Wing Section of the
   XP-51 Airplane with Beveled Trailing-Edge and
   Contour Ailerons. NACA MR, Jan. 27, 1943.

TABLE I

AIRFOIL ORDINATES OF INTERMEDIATE WING SECTION OF XP-51 AIRPLANE

Plain wing section				Modified wing section		
x/c	y_U/c	y_L/c		x/c	y_U/c	y_L/c
0	0	0		0	0	0
.0125	.0184	-.0134		.0125	.0184	-.0134
.025	.0267	-.0181		.025	.0267	-.0181
.05	.0368	-.0249		.05	.0368	-.0249
.075	.0438	-.0304		.075	.0438	-.0304
.10	.0500	-.0349		.10	.0500	-.0349
.15	.0598	-.0412		.15	.0598	-.0412
.20	.0664	-.0464		.20	.0664	-.0464
.25	.0717	-.0506		.25	.0717	-.0506
.30	.0763	-.0546		.30	.0763	-.0546
.35	.0787	-.0550		.35	.0787	-.0550
.40	.0793	-.0552		.40	.0793	-.0552
.45	.0790	-.0545		.45	.0790	-.0545
.50	.0769	-.0530		.50	.0769	-.0530
.60	.0675	-.0447		.60	.0675	-.0447
.70	.0520	-.0319		.70	.0520	-.0319
.80	.0338	-.0168		.80	.0328	-.0173
.805	.0326	-.0163		.85	.0220	-.0080
.8125		-.0156				
.815		-.0154				
.8175		-.0151				
.82		-.0143				
.85	.0228	-.0113				
.90	.0133	-.0066				
.95	.0056	-.0024				
.998	.0011	-.0011				
1.000	0	0				

A - ORIGINAL (REF. 3)

.813c

B - REFERENCES 1 AND 3

.85c

.008c GAP

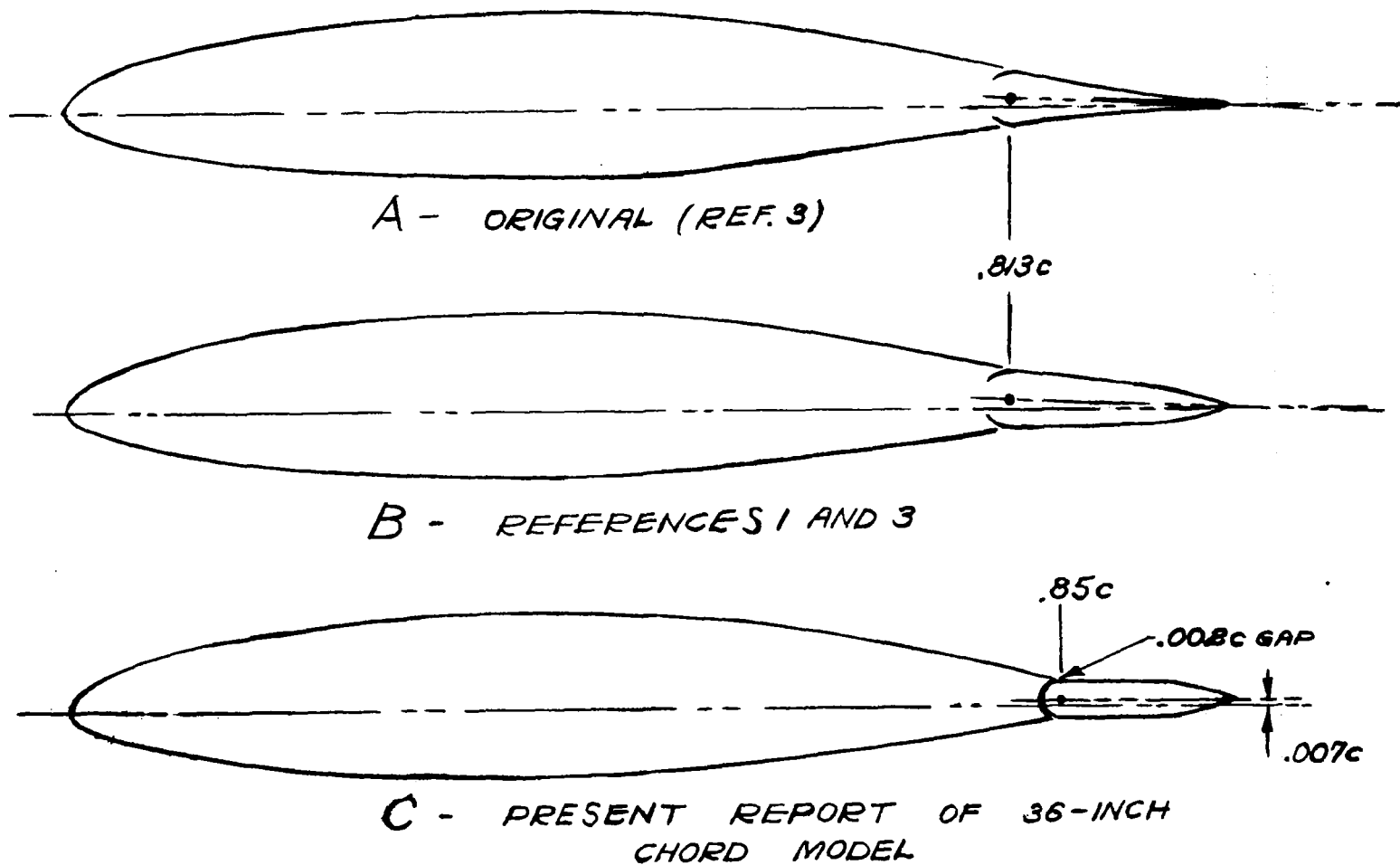.007c

C - PRESENT REPORT OF 36-INCH
CHORD MODEL

Figure 1.- Comparison of aileron shapes tested for XP-51
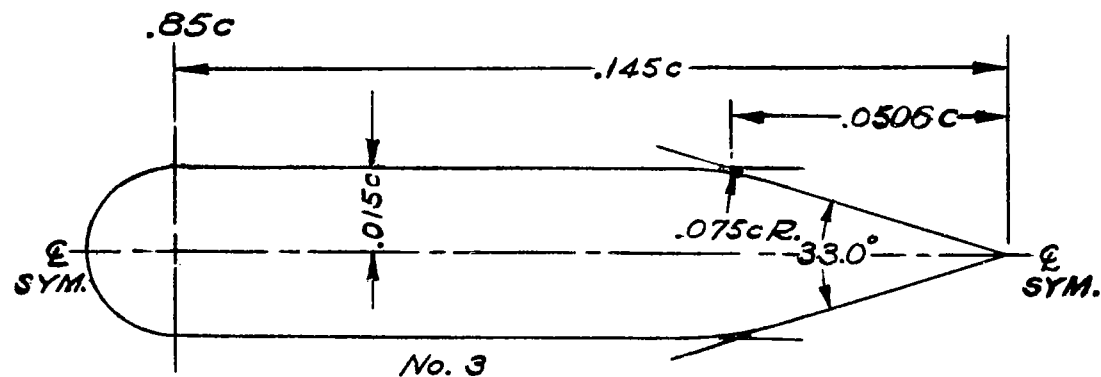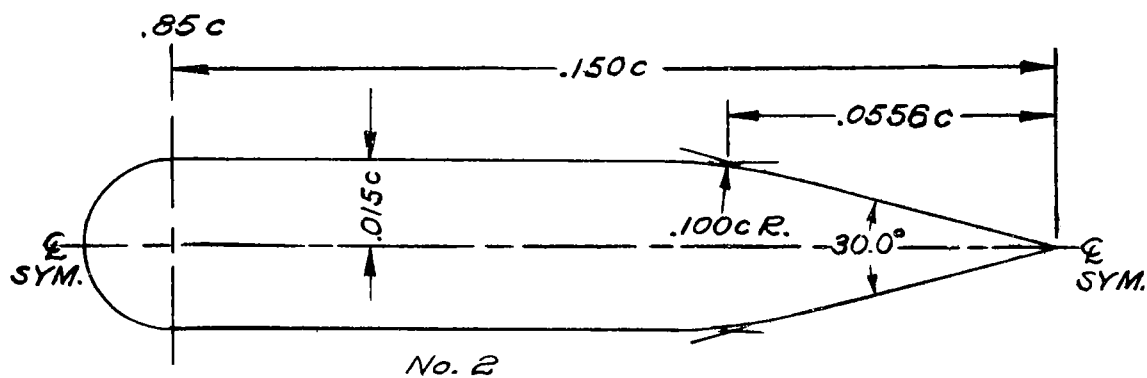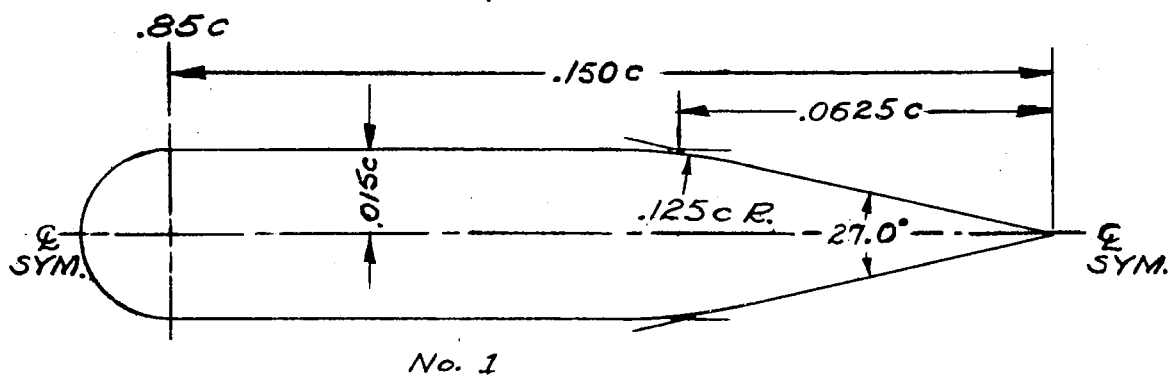airplane. Configuration C is model configuration
reported herein.

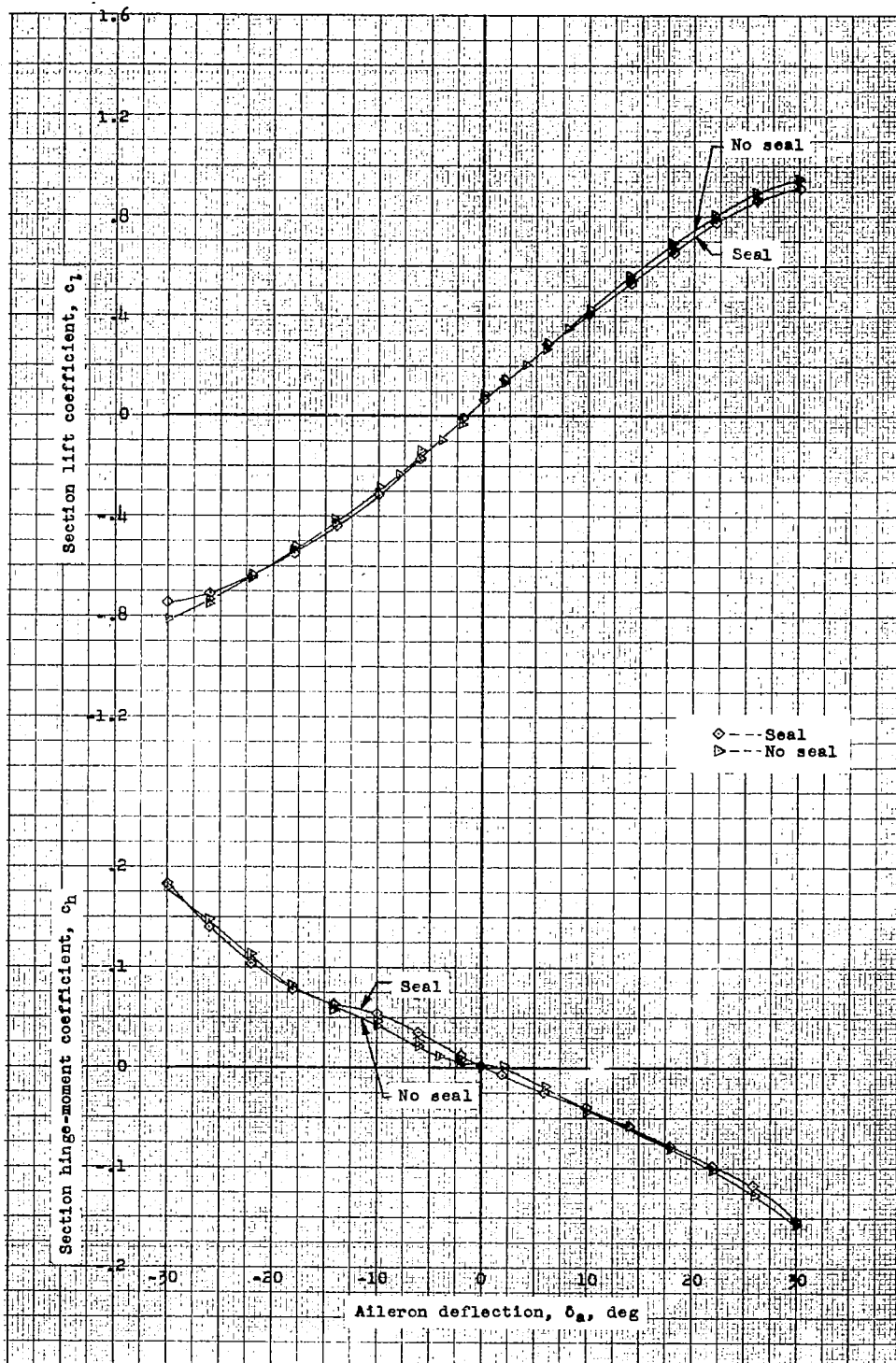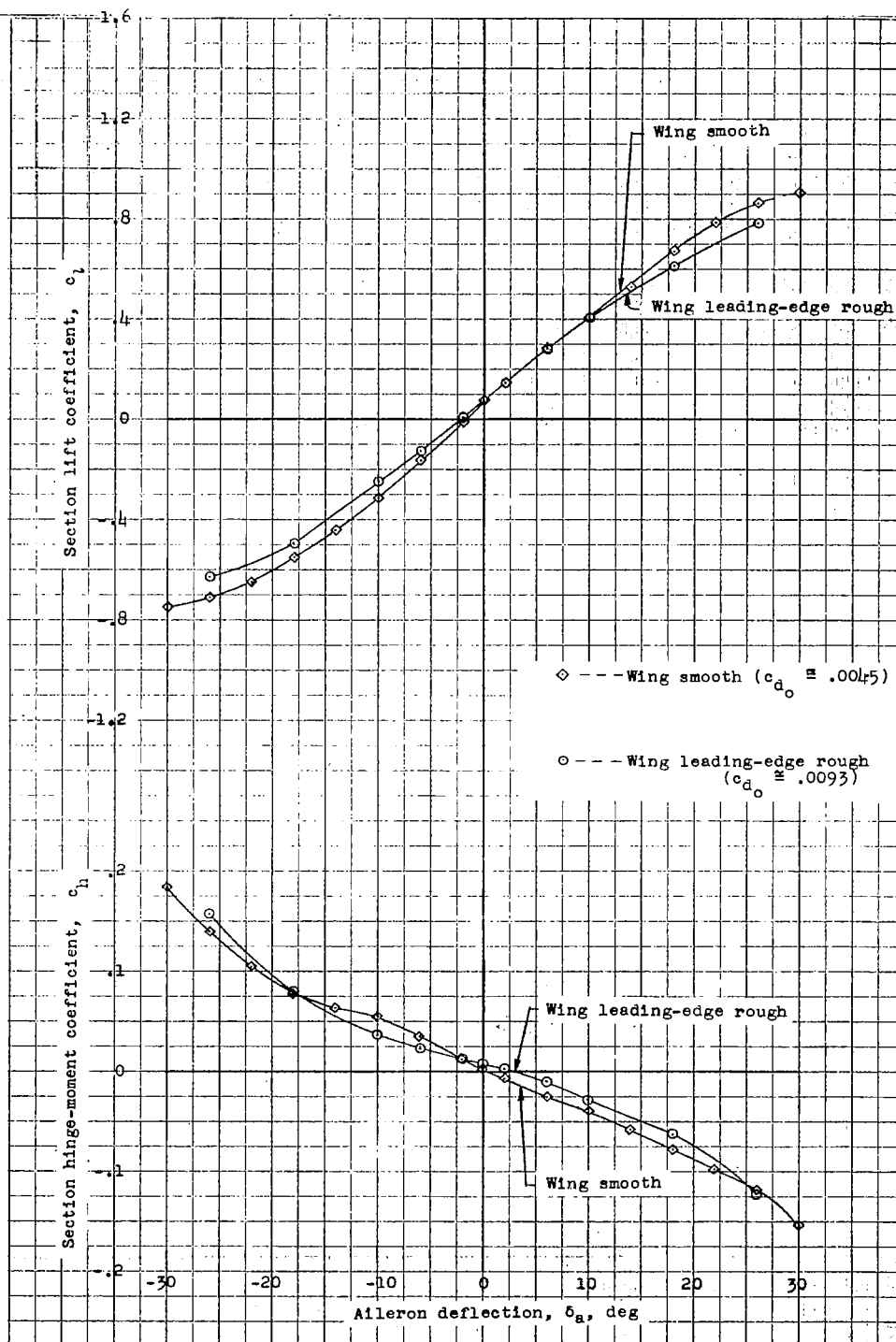Figure 2.— Aileron shapes tested on 36-inch chord model of XP-51 wing section.
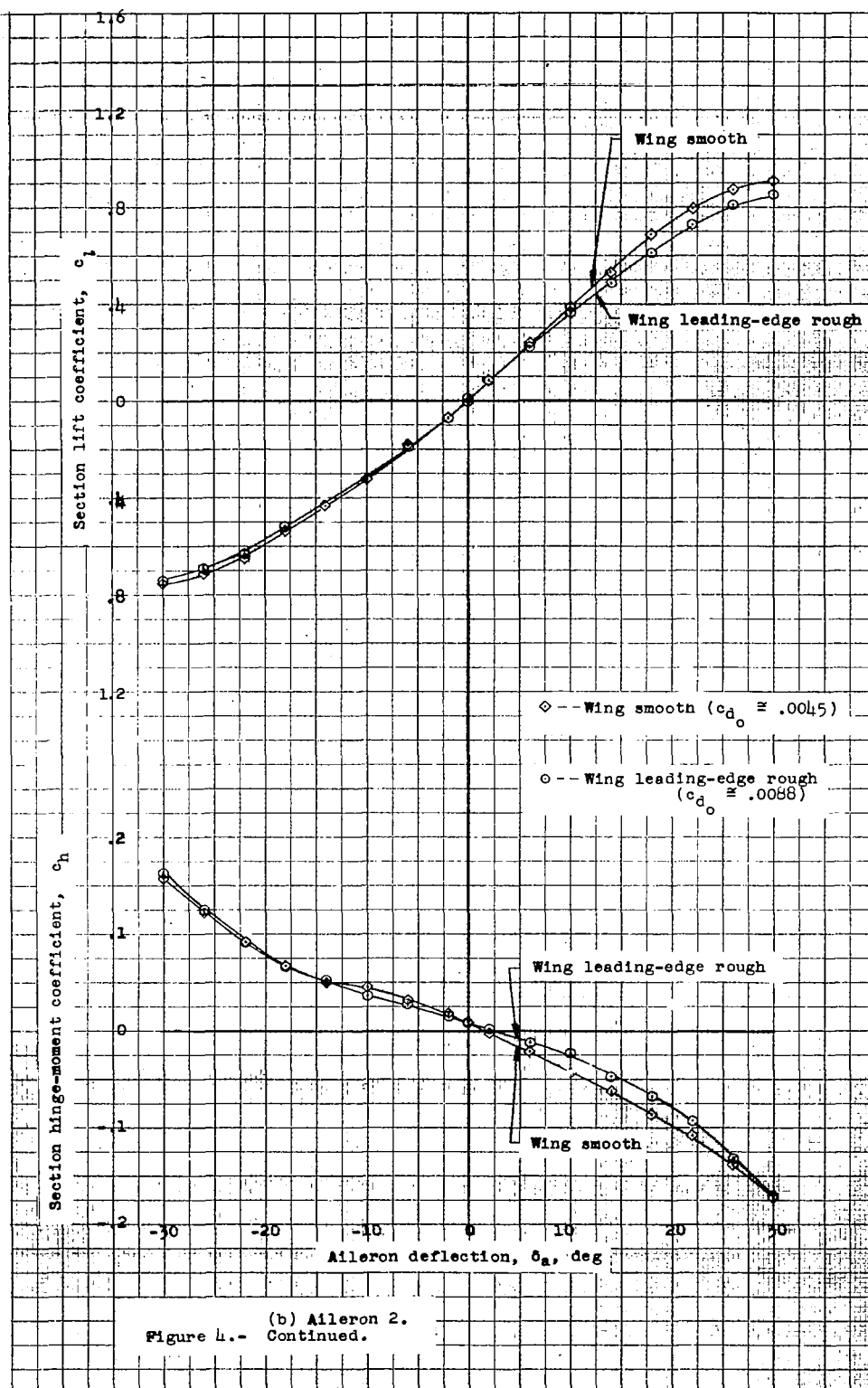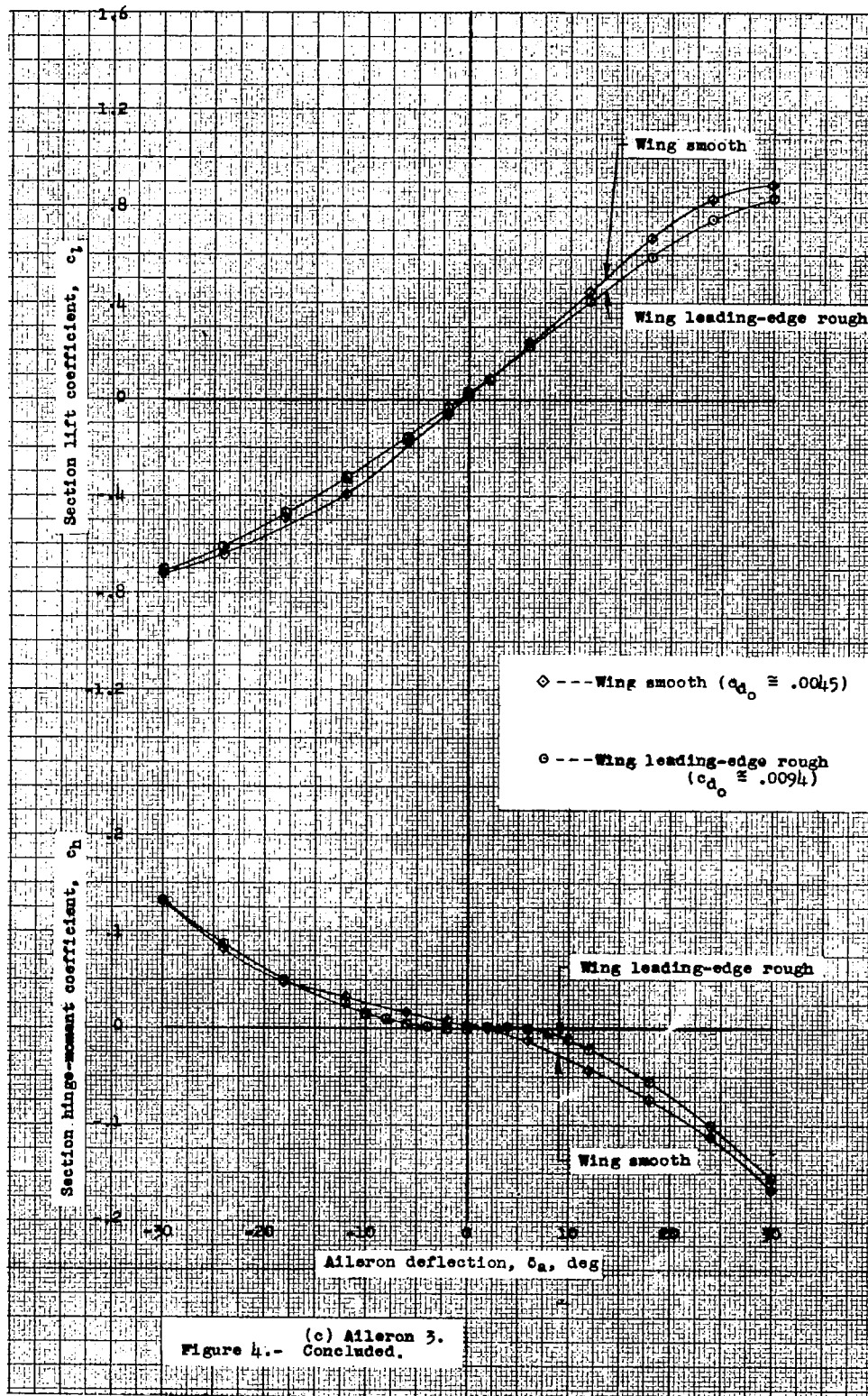
Figure 3.- Effect of hinge gap on section aileron characteristics
of aileron 1 on a scale model of the intermediate wing section of
the XP-51 airplane. $a_0, 0°$; wing smooth ($c_{d_0} \cong .0045$); R, 4×10^6.

(a) (Aileron 1.

Figure 4.- Effect of wing leading-edge roughness on section
aileron characteristics of a modified aileron on a scale
model of the intermediate wing section of the XP-51 airplane.
a_o, $0°$; sealed; R, 4×10^6.

(b) Aileron 2.
Figure 4.- Continued.

Section lift coefficient, c_l

Section hinge-moment coefficient, c_h

Wing smooth

Wing leading-edge rough

Wing leading-edge rough

Wing smooth

$\Diamond$ ---Wing smooth ($c_{d_o} \cong .0045$)

$\ominus$ ---Wing leading-edge rough
($c_{d_o} \cong .0094$)

Aileron deflection, δ_a, deg

(c) Aileron 3.
Figure 4.- Concluded.

Modified aileron section - aileron 1

$\odot$ ─ ─ Seal
+ ─ ─ No seal $\quad \delta_a, 0°; R, 4 \times 10^6$

─────────── Plain wing section; R, 6×10^6 (fig. 5 - ref. 3)
─ ─ ─ ─ ─ Plain wing section with 0.187c contour aileron;
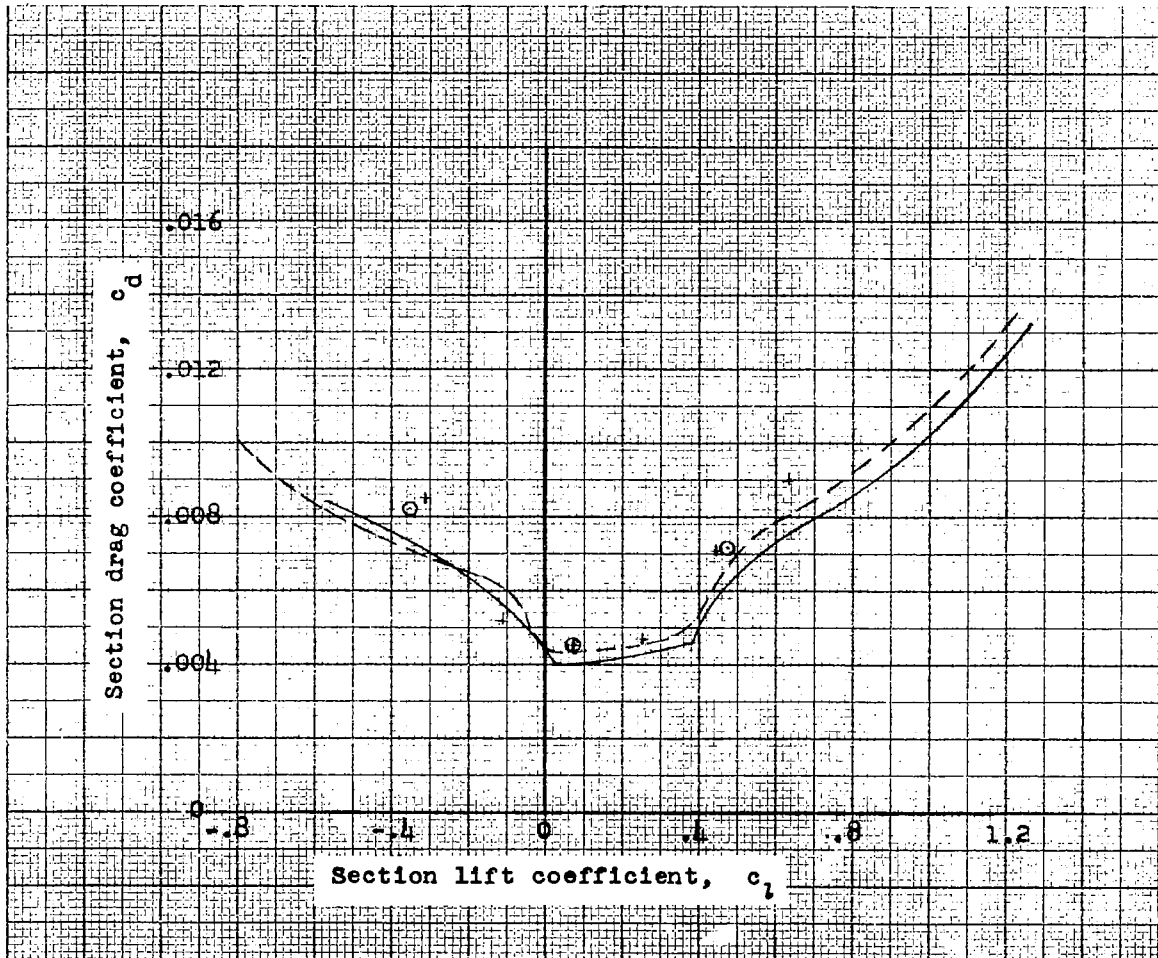R, 6×10^6; no seal. (fig. 10 - ref. 3)

Figure 5.- Comparison of the drag polars of the modified
wing section with aileron 1 and the plain wing with and
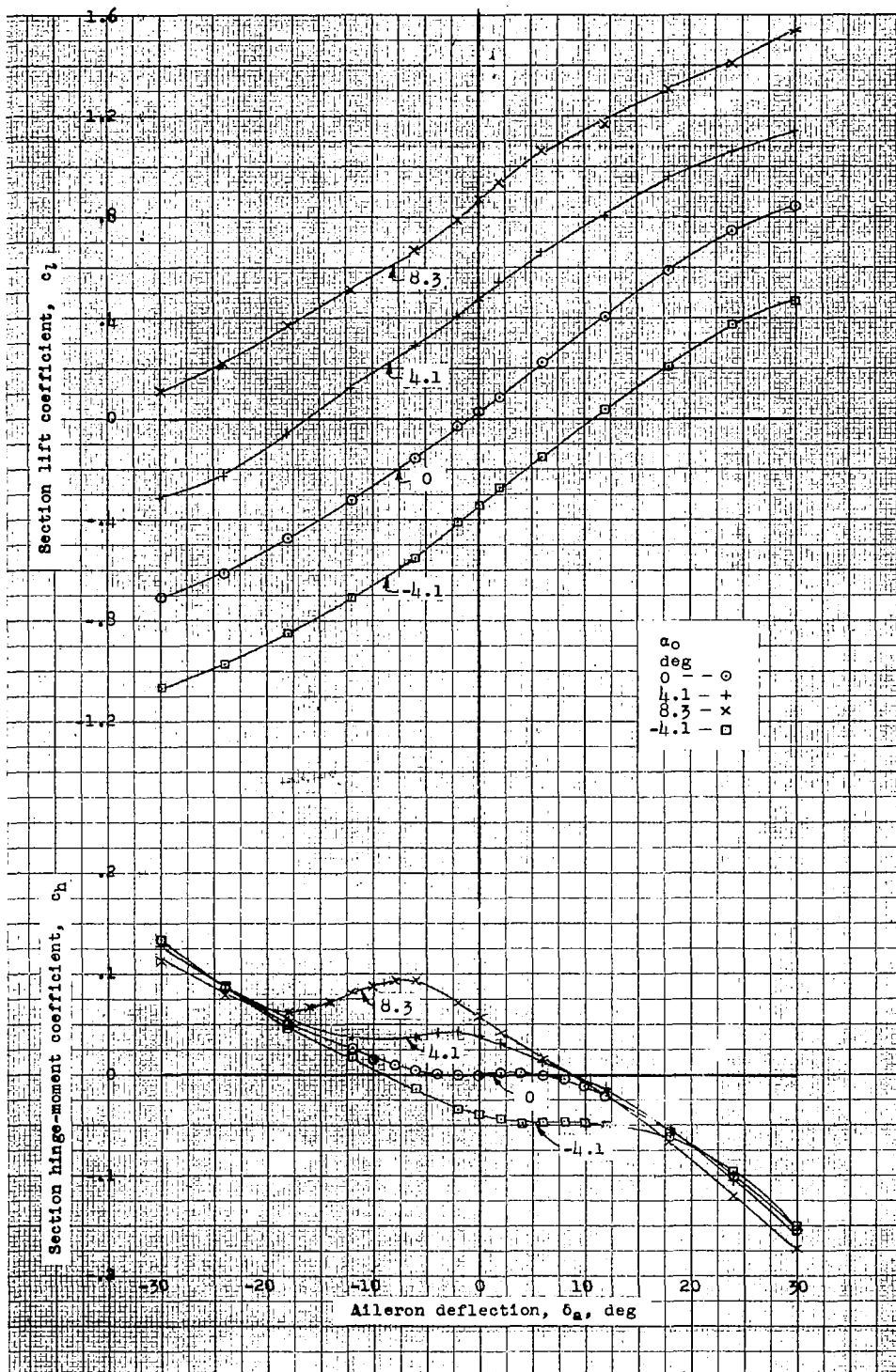without a contour aileron.

Figure 6.- Section aileron characteristics of aileron 3 on a scale model of the intermediate wing section of the XP-51 airplane. Wing leading-edge rough, sealed; R, 4×10^6.